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A simple novel method for considering static voltage stability indicator in a power system

By

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Abstract:

The voltage stability is the ability of the power system to provide adequate reactive power under all operating conditions and to maintain stable load voltage magnitude within specified operating limits. The voltage instability leading to collapse appears to be due to the inability of networks to meet a demand for reactive power at certain critical or weak buses. It can be recognized by noting excessive fall in voltage for small increase in load and increasing difficulty in controlling system voltage. Therefore voltage collapse prediction must take in consideration in power system planning and operation. In this paper a novel indicator from a parallel algorithm will be presented to predict the voltage instability or the proximity of a collapse. The indicator uses the obtained data of a normal load flow to identify the weak buses in the power system. This method has carried out over changing the load power factor. Obtained results for the IEEE 5 bus system considering the effects of STATCOM on voltage stability are presented and discussed.

Keywords:

Voltage Stability, Voltage Instability, Voltage Collapse, Voltage collapse prediction, Voltage Collapse Indicator, FACTS devices and Parallel algorithm.

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1. Introduction:

Voltage instability problem is one of the major problems facing the electric power utilities in many countries. It is also a main concern in power system operation and planning [1].The problem of voltage instability can be explained as the ability of a power system to maintain steady acceptable voltages at all buses in the system at normal operating conditions and after being subjected to a disturbance [3]. Voltage collapse is the result of a sequence of events that leading to decrease of the system voltage profile which starts gradually and then decreases rapidly suddenly in a major part of the power system [2]. It has been found that voltage magnitudes do not give a good indication of proximity to voltage stability limit [4]. There are a lot of different Indices have been proposed in [5, 6]. The effects of FACTS devices on voltage stability are presented in [7:10]. The objective of this paper is to develop a simple novel indicator from a parallel algorithm by using the obtained data of the load flow problem of large power system for considering voltage stability margin [11:15].
The proposed indicator is based on the Gauss-seidel algorithm which usually used in the solution of load flow problem and studying the effect of FACTS devices on voltage stability margin. This index of the voltage stability, which is derived from the computational techniques for voltage stability assessment, predicts the voltage problem of the system with sufficient accuracy.

2.Fundamentals: Single Generator and Load system:

A simple power system is considered, through which the indicator of the voltage stability is derived. As shown in fig. (1), bus 1 is a generator bus and bus 2 is a load bus whose voltage behavior will be investigated. Test study will be carried out for two cases: (i) Base case, (ii) when installing a STATCOM (capacitor bank) when voltage $\leq$0.95p.u.

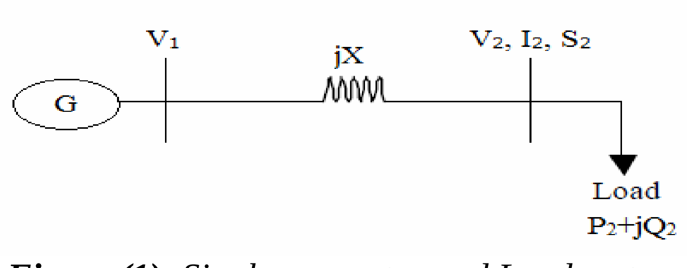

Figure (1): *Single generator and Load system*

2.1 Base case:

This simple system can be described by the following equations (where the dot above a letter represents a vector):

$$\dot{I}_2 = \frac{\dot{V}_1 - \dot{V}_2}{\dot{X}} = \frac{\overset{*}{S}_2}{\overset{*}{V}_2} \qquad (1)$$

$$\overset{*}{S}_2 = \frac{\dot{V}_1 \overset{*}{V}_2}{\dot{X}} - \frac{V_2^2}{\dot{X}} \qquad (2)$$

To solve for $|\dot{V}_2|$, equation (2) will be solved, with the assumption that $\overset{*}{S}_2 \dot{X} = a + jb$

Then,

$$\overset{*}{S}_2 \dot{X} = a + jb = \dot{V}_1 \overset{*}{V}_2 - V_2^2$$
$$= V_1 V_2 \operatorname{Cos}(\delta_1 - \delta_2) + jV_1 V_2 \operatorname{Sin}(\delta_1 - \delta_2) - V_2^2 \qquad (3)$$

Where: δ_1, δ_2 Are the sending end and receiving end angle, respectively.

$$\operatorname{Cos}(\delta_1 - \delta_2) = \frac{a + V_2^2}{V_1 V_2}$$
$$\operatorname{Sin}(\delta_1 - \delta_2) = \frac{b}{V_1 V_2} \qquad (4)$$

From equation (4) then,

$$V_1^2 V_2^2 = (a + V_2^2)^2 + b^2 = a^2 + 2aV_2^2 + V_2^4 + b^2 \qquad (5)$$

Solve equation (5) to obtain:

$$V_2 = \sqrt{(V_1^2/2) - a \pm \sqrt{(V_1^4/4) - aV_1^2 - b^2}} \qquad (6)$$

The obtained voltage has four solutions; only two solutions have physically meaning. These two solutions corresponding to high value and low value of voltage.
The voltage at bus 2 will be collapses, if $(V_1^4/4) - aV_1^2 - b^2 = 0$

When the voltage collapses, it is said that $V_2^2 = \frac{V_1^2}{2} - a$ (7)

From equation (7), an indicator of the voltage stability will be proposed as:

The Indicator = $1 - (2V_2^2 - V_1^2 + 2a) = 1 - (2V_2^2 - V_1^2 + 2Q_2 X)$ (8)

Then, the derived indicator can be used for predicting the voltage stability problem of the system. The indicator will vary in the range between 0 (no-load of system) and 1 (the voltage at the load bus will collapse).
One example of a single generator and load system was built to determine the proposed indicator, $V_1 = 1.0\angle 0^\circ$; $X = j0.25$
For each power factor the load at bus 2 will be changed continuously to find the

collapse point of the system.

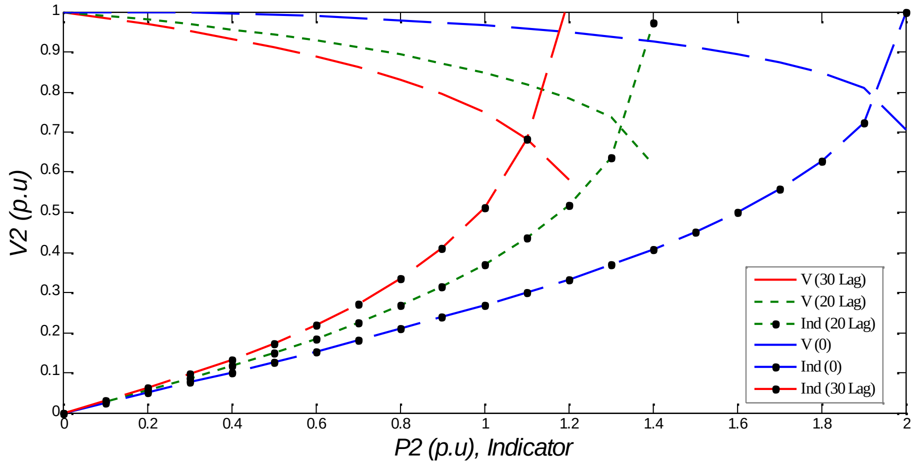

Figure (2): *PV Curves and indicators at constant power factor*

2.2 When installing a STATCOM:

By installing a STATCOM in bus 2, the system loading will be increased and the system stability margin will be increased as shown in Fig.3.

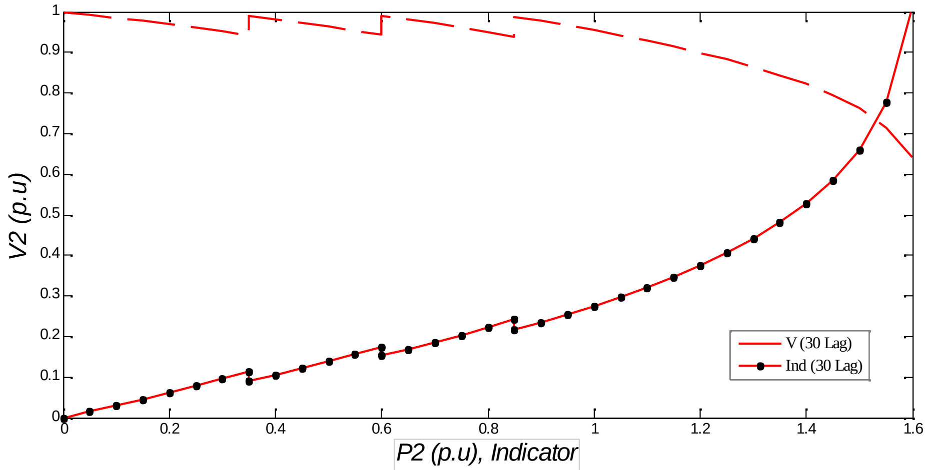

Figure (3): *PV Curve and indicator at installing a STATCOM*

3.Generalization to an N-bus System:

The results obtained from load flow study are used to deduce the novel indicator using parallel algorithm. The idea of parallel processing method starts with transformation of an n-machine system into n-equivalent single machine to equivalent bus [15]. All the buses can be divided into two categories: Generator bus (PV bus and Slack bus) and Load bus (PQ bus). A single line diagram of the power system is considered to obtain an equivalent model, which is denoted by a single machine to equivalent bus as shown in fig. (4).

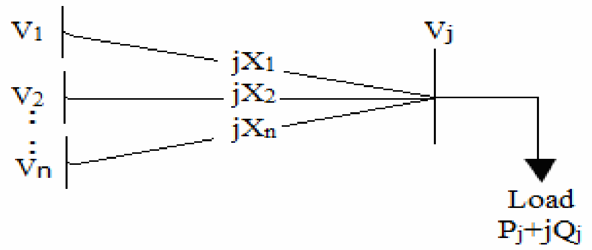

Figure (4): *A group of buses are connected to load bus j*

The injected current at the load bus will be determined by:

$$\dot{I}_j = \frac{\overset{*}{S}_j}{\overset{*}{V}_j} = \sum_{i=1}^{n} \left(\frac{\dot{V}_i - \dot{V}_j}{\dot{X}_i} \right) \tag{9}$$

$$\text{Where: } \dot{V}_i = V_i \, e^{j\alpha_i} \quad ; \quad \dot{V}_j = V e^{j\alpha_j}$$

Rearrange the pervious equation , we obtain:

$$P_j = V_j \sum_{i=1}^{n} \frac{V_i}{X_i} \mathrm{Sin}(\alpha_i - \alpha_j)$$

$$Q_j = V_j \sum_{i=1}^{n} \frac{V_i}{X_i} \mathrm{Cos}(\alpha_i - \alpha_j) - V_j^2 \sum_{i=1}^{n} \frac{1}{X_i} \tag{10}$$

From the equivalent bus shown in fig. (5). Another formula for the injected current at load bus can be obtained, as given in equation (11)

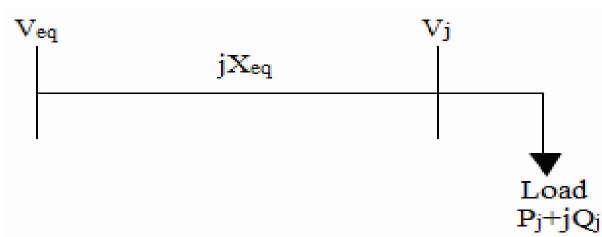

Figure (5): *Equivalent bus connected to load bus j*

$$\dot{I}_j = \frac{\overset{*}{S}_j}{\overset{*}{V}_j} = \left(\frac{\dot{V}_{eq} - \dot{V}_j}{\dot{X}_{eq}} \right) \tag{11}$$

$$\text{Where: } \dot{V}_{eq} = V_{eq} e^{j\alpha_{eq}}$$

The following equations will be derived.

$$P_j = \frac{V_j V_{eq}}{X_{eq}} \operatorname{Sin}(\alpha_{eq} - \alpha_j)$$
$$Q_j = \frac{V_j V_{eq}}{X_{eq}} \operatorname{Cos}(\alpha_{eq} - \alpha_j) - \frac{V^2}{X_{eq}} \qquad (12)$$

Comparing the two equations (10) With the two equations (12) Respectively, the equivalent parameters will be obtained.

$$\frac{1}{X_{eq}} = \sum_{i=1}^{n} \frac{1}{X_i}$$
$$V_{eq} = X_{eq}\sqrt{(A)^2 + (B)^2} \qquad (13)$$
$$\alpha_{eq} = \operatorname{Tan}^{-1}(\frac{A}{B})$$

$$\text{Where}: \ A = \sum_{i=1}^{n} \frac{V_i}{X_i} \operatorname{Sin}\alpha_i \quad ; \quad B = \sum_{i=1}^{n} \frac{V_i}{X_i} \operatorname{Cos}\alpha_i$$

From equations (12).

$$\operatorname{Sin}(\alpha_{eq} - \alpha_j) = \frac{P_j X_{eq}}{V_j V_{eq}}$$
$$\operatorname{Cos}(\alpha_{eq} - \alpha_j) = \frac{Q_j X_{eq} + V_j^2}{V_j V_{eq}} \qquad (14)$$

From equations (14).

$$V_j^4 + bV_j^2 + c = 0 \qquad (15)$$
$$\text{Where}: \ b = 2Q_j X_{eq} - V_{eq}^2 \quad ; \quad c = X_{eq}^2 (P^2 + Q^2)$$

Solve equation (15), the voltage will have four solutions, two of them have physical meaning. These two solutions will correspond to the high and the low value of voltage. The voltage at bus j will collapse, if $b^2 - 4c = 0$

i.e., $V_j^{\ 2} = \frac{-b}{2}$ (16)

From equation (16), the proposed indicator of the voltage stability of the load bus j will be easily obtained as :

$$\text{Indicator}_j = 1 - (2V_j^{\ 2} + b) = 1 - (2V_j^2 + 2Q_j X_{eq} - V_{eq}^2) \qquad (17)$$

The indicator for the power system can be obtained by:

$$\text{Indicator}_{system} = \max_{j \in L} (\text{Indicator}_j)$$

Then an indicator, which can be used for predicting the voltage stability problem of the power system, has been derived from parallel processing. Thereby, it is clear that the indicator of the voltage stability at any load bus mainly influenced by two parts: the load at bus j itself, and the 'contributions' of the other load buses as shown at equation (13). If the load at a load bus is changed, the indicator will be influenced; therefore the voltage stability problem is a system-wide problem and not a local one.

3.1 Case study:

The proposed approach is adapted on IEEE 5-bus, with bus1 is taken as Slack bus. The system is shown in fig. (6).

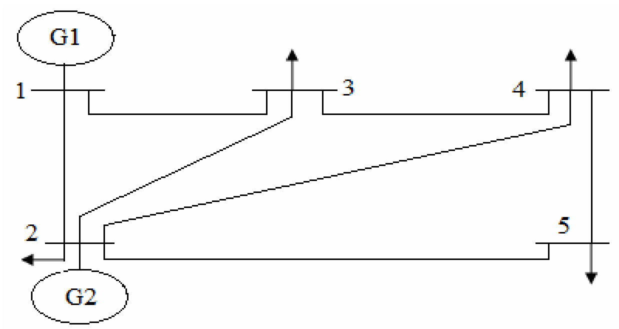

Figure (6): *IEEE 5-bus system*

3.1.1 Case one:

When the load increase at all buses. The indicator will provide that bus 5 will be collapsed. The voltage stability margin based on the computed indicator as shown in fig. (7).

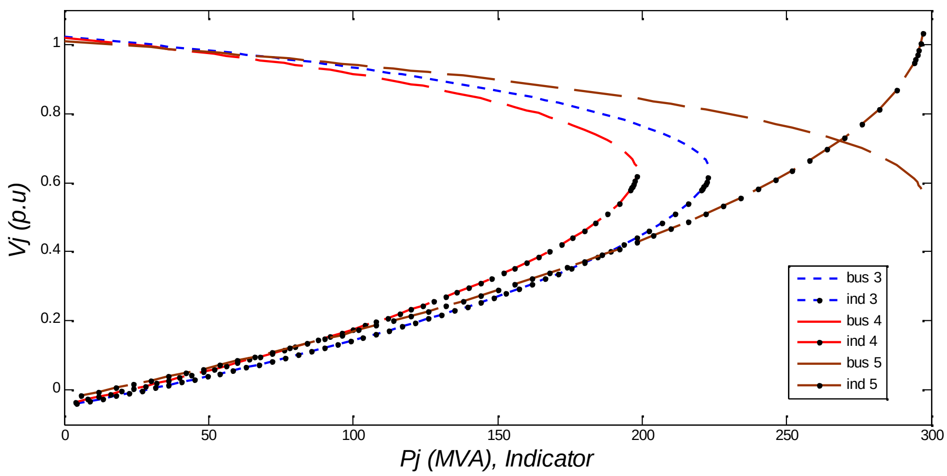

Figure (7): *IEEE 5-bus system (case one) all loads increase*

3.1.2 Case two:

When the load at bus 5 increased with a constant power factor. The indicator is continuously increasing as the load increases as shown in fig. (8).

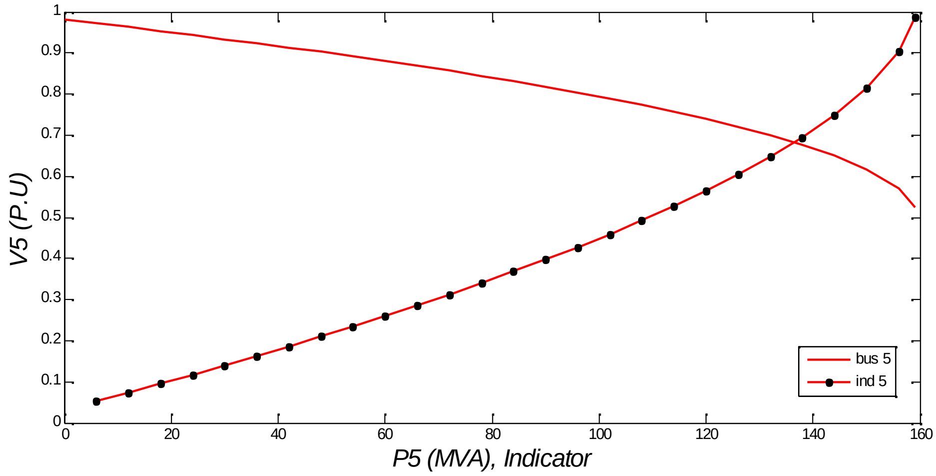

Figure (8): *IEEE 5-bus system (case two) loads at bus 5 increase*

3.1.3 Case three:

The load at bus 5 will increase results a decrease in the voltage level at all buses. The indicator will provide that bus 5 is collapsed and by installing a STATCOM the voltage stability will be improved and the system loading will be increased. The system stability margin is shown in fig. (9).

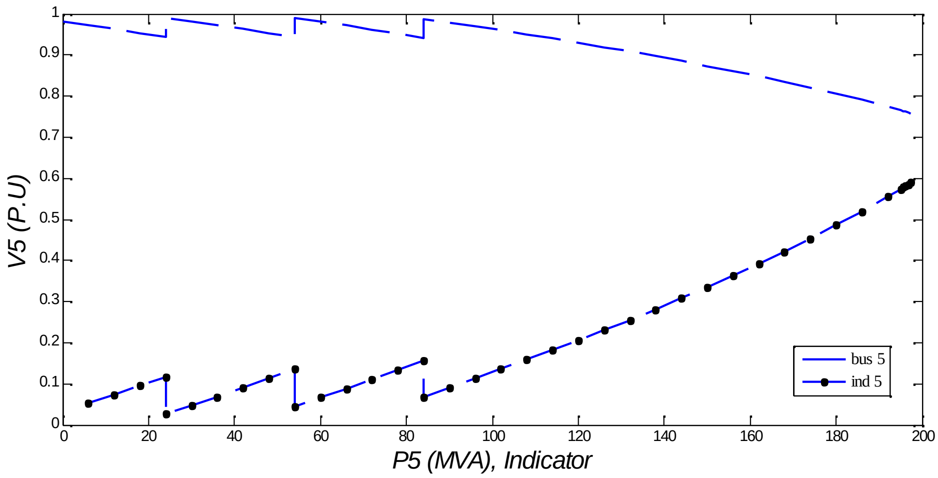

Figure (9): *IEEE 5-bus system (case three) load at bus 5 increases, installing a STATCOM*

4. Conclusions:

A novel indicator from a parallel algorithm for considering voltage stability of the power system is presented. The indicator can predict the voltage stability problem correctly and properly by using steady-state data. Through the indicator, it is very easy to determine the weak buses of the system and the collapse point of the system can easily predicted. The using of STATCOM will improve the voltage stability and the system stability margin.

References:

[1] P. A. Lof, G. Anderson, and D. J. Hill, "*Voltage Stability Indices For Stressed Power System*," IEEE Trans. on Power Systems, vol. 8, pp. 326-335, Feb. 1993.

[2] Kessel P, Glavitsch H. "*Estimating the voltage stability of a power system*", IEEE Trans Power Delivery 1986; PWRD-1(3):346–54.

[3] Nan Cutsem T. and Vournas C., "*Voltage Stability of Electric Power Systems*", Kluwer academic publishers, Boston, USA, 1998, 378 p.

[4] Clark HK. New challenges: *voltage stability*, IEEE Power ENG. Rev 1990; April:33–7

[5] J.H.CHOW, F.F.WU, J.A.MOMOH, "*Applied Mathematics for Restructured Electric Power Systems Optimization, Control, and Computational Intelligence*", Springer US, ISBN 978-0-387-23471-7 (Online), 2005, pp. 25-37.

[6] H.S.Xiaoxin, Z.R.Li, "*Accuracy Analysis of Static Voltage Stability Indices Based On Power Flow Model*", Transmission and Distribution Conference and Exhibition: Asia and Pacific, 2005 IEEE/PES, 2005, pp.1-7.

[7] X.P.Zhang, C.Rehtanz, B.Pal, "*Flexible AC Transmission Systems: Modeling and Control*", Springer, Berlin, 2006, pp. 189-216.

[8] R. Natesan, G. Radman, "*Effects of STATCOM, SSSC and UPFC on voltage stability*", Proc. of the Thirty- Sixth Southeastern Symposium, 2004, pp.546 – 550.

[9] J.M.Ramirez, J.L.Murillo-Perez, "*Steady-state voltage stability with Stat COM*", IEEE Trans. On Power Systems, Vol. 21, Issue 3, Aug., 2006, pp. 1453 – 1454.

[10] A.R. Messina, M.A. Pe´rez, E. Herna´ndez, "*Coordinated application of FACTS devices to enhance steady-state voltage stability*", International Journal of Electrical Power & Energy Systems, Volume 44, Issue 6, 2003, pp. 259–267.

[11] Hariri s. and Parashar M., "*Tools and Environments for Parallel and Distributed Computing*", Wiley- IEEE, 2004

[12] Koester D. P., Ranka S., and Fox G. C., "*A Parallel Gauss-Seidel Algorithm for Sparse Power System Matrices*", in Proceedings of Supercomputing, pp. 184-193, 1994.

[13] "*PVM: Parallel Virtual Machine*," available at: http://www.csm.ornl.gov/pvm/.
[14] Wikipedia, "*Parallel Virtual Machine*", The free Encyclopedia, available at: http://en.wikipedia.org/wiki/pvm.
[15] M. A. Ali and W. M. Mansour: "*A Proposed Approach for Online Transient Stability of Multimachine Power Systems Using Parallel Microprocessors*", ICEENG 2008 proceedings, EE149, pp: 901-910.

Nomenclatures:

$\delta_1, \delta_2 \ldots$ Voltage angle of sending end and receiving end respectively
$\alpha_{eq} \ldots$ Voltage angle of the equivalent bus
$\dot{I}_j \ldots$ Injected current at load bus-j
$P_j \ldots$ Injected active power at bus-j
$Q_j \ldots$ Injected reactive power at bus-j
$S_j \ldots$ Injected apparent power at bus-j
$\dot{V}_i, \dot{V}_j \ldots$ Voltage of bus-i, and bus-j respectively
$\dot{V}_{eq} \ldots$ Voltage of equivalent bus